MARITIME UNIVERSITY OF SZCZECIN

ORGANIZATIONAL UNIT:
DEPARTMENT OF MARINE COMMUNICATION TECHNOLOGIES

INSTRUCTION

ELECTRICAL ENGEENERING AND ELECTRONICS
Laboratory
Exercise No 8: Amplifiers

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Contents

8. AMPLIFIERS

8.1. The purpose and scope of the exercise

The aim of the exercise is to master knowledge of the construction, parameters, characteristics and application of basic amplifiers systems.

Topics

1. The concept of an amplifier.
2. Classification of amplifiers.
3. Parameters of amplifiers.
4. Characteristics of amplifiers.
5. Power amplifiers.
6. Selective amplifiers.
7. The influence of negative feedback on the amplifier's operation.

Control questions.

1. Explain what device we call the amplifier?
2. Provide a classification of amplifiers due to different accepted criteria.
3. Provide the basic parameters of the amplifiers.
4. Draw and characterize the substitute diagram of the reinforcement system.
5. Characterize and describe the individual parameters of the amplifiers.
   - strengthening,
   - efficiency
   - input and output impedances
   - rated parameters
   - frequency response
   - dynamic work range
6. List and characterize the characteristics of the amplifiers.
7. Describe exactly the frequency characteristics of the amplifiers.
8. Characterize the dynamic (transient) characteristics of the amplifier.
9. Describe the line distortion of the amplifier.
10. Describe the nonlinear distortion of the amplifier.
11. Describe multistage amplifiers.
12. Characterize power amplifiers
13. Characterize selective amplifiers (tuned, resonant).
14. What is the feedback loop? Give basic dependencies.
15. What is positive feedback (PFB)?
16. What is negative feedback (NFB)?
17. For what purpose is the NFB used?
18. Provide NFB classification.
19. Explain the effect of NFB on the parameters of the amplifier.

8.2. Description of the measurement system.

A set of instruments:

a. test system;
b. two-channel oscilloscope,
c. 9V power supply,
d. sine wave generator

Description of the laboratory stand.

The system consists of one plate powered with 9V DC. It contains a typical simplest one-stage amplifier built on the *T* transistor. The input signal from the generator is given to one of the inputs W_{e1} or W_{e2}. Both inputs differ only in the coupling capacity (capacitors C_1 and C_2). The amplified signal output is observed using a oscilloscope from the *Wy* sockets The amplifier can work as a broadband amplifier - then as the collector load there is a resistance *R*, or as a resonant amplifier - then in the collector circuit there is an *LC* resonant circuit. The output signal is observed from the collector of the transistor through the coupling capacity C_3. It is possible to observe the amplified signal without attaching the output resistance (R_{wy1} and R_{wy2} disconnected) or connecting the output resistance. They may, for example, represent the input resistance of another device connected to the amplifier or the input resistance of the next amplifying stage.

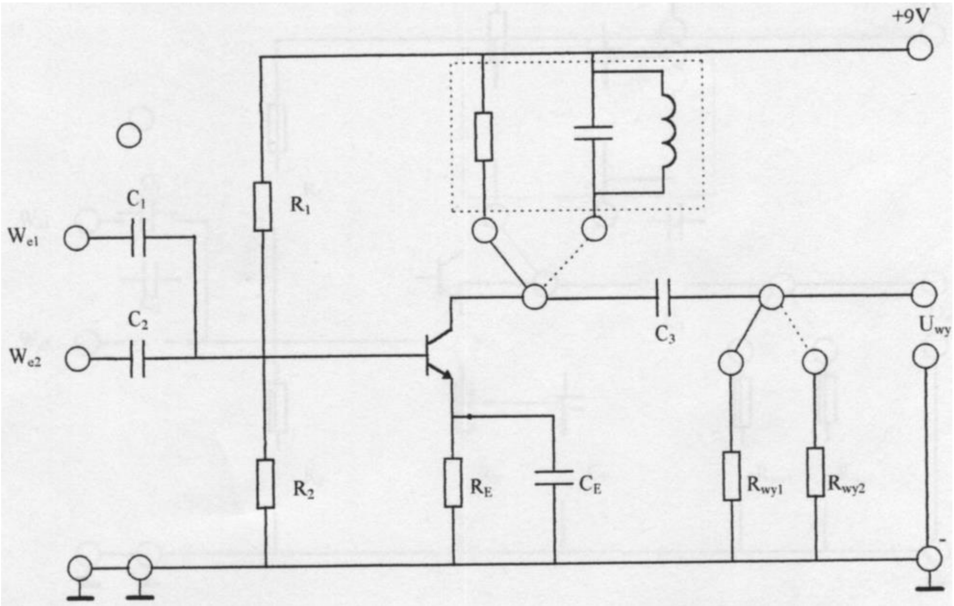


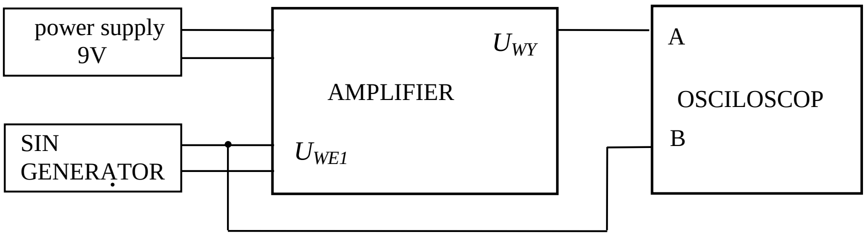
Fig. 8.2.1. Diagram of the tested system.

8.3. Execution of the exercise

Connect the 9V supply voltage to the test system **(only with the consent of the teacher)**.

8.3.1. est of transient (dynamic) characteristics of an amplifier $U_{wy} = f(U_{we})$

Switch the amplifier to a bandwidth amplifier (collector resistance load). Connect the system as shown in Fig. 8.3.1.



Rys. 8.3.1. Connection diagram for transient characteristics testing.

Set on the generator:

$f = 10$ kHz.

Connect the voltage from the generator to the sockets W_{WE1}, disconnect any connected loads - R_1 and R_2. identify the transient (dynamic) characteristics of the amplifier $U_{wy} = f(U_{we})$ setting the input voltage amplitude to an oscilloscope - U_{we} from 50 mV up 50 mV:

$U_{we} = \{50, 100, 150, \ldots\}$ [mV]

measuring the amplitude of the output voltage - U_{wy} on the second channel pf osciloskope.

Note: For DM3051 generators, the value to be set is the peak-to-peak value - Up-p instead of amplitude - Uo. Therefore, the voltage set on the generator must be 2 times higher than that required in the measurement card.

Observing the shape of the output voltage, determine at what amplitude of the input voltage there was a clear distortion of the signal at the output.

8.3.2. Determination of amplitude and phase characteristics of a broadband amplifier for different coupling capacities

Disconnect any connected loads - R_1 and R_2. Set the input voltage amplitude:

$U_{we} = 100$ mV

a. Connect the sinusoidal waveform generator to the amplifier via the coupling capacity.:

$C_1 = 0.1$ μF (socket We1)

Determine amplitude-frequency characteristics of the amplifier $U_{wy} = f(f)$ measuring the voltage amplitude of the output - U_{wy} and phase characteristics of the amplifier by measuring phase shift $\phi = f(f)$ between the input and output waveforms, changing the frequency f from 10 Hz to 100 kHz:

$f = \{10, 20, 50, 100, 200, 500, 1000, \ldots 100\,000\}$ [Hz]

b. Connect the sinusoidal waveform generator to the amplifier via the coupling capacity:

$C_2 = 0.01$ μF (socket We2)

Determine amplitude-frequency characteristics of the amplifier $U_{wy} = f(f)$ measuring the voltage amplitude of the output - U_{wy} and phase characteristics of the amplifier by measuring phase shift $\phi = f(f)$ between the input and output waveforms, changing the frequency f from 10 Hz to 100 kHz:

f = {10, 20, 50, 100, 200, 500, 1000, …100 000} [Hz]

8.3.3. Determination of amplitude-frequency characteristics of a resonant amplifier (selective, narrowband) for different output resistors

Switch the amplifier to a resonance amplifier (collector *LC* load). Connect the sinusoidal waveform generator to the amplifier via the coupling capacity. C_1 = 0.1 μF (gniazda We1). Set the input voltage amplitude:

U_{we} = 10 mV

Determine amplitude-frequency characteristics of the resonant amplifier $U_{wy} = f(f)$ measuring the voltage amplitude of the output U_{wy} changing the frequency f in ranges from 12 to 28 kHz step 1 kHz:

f = {12, 13, …28} [kHz]

for three different output resistances R_{wy}:

a. $R_{wy} = \infty$ (load cable disconnected)
b. R_{wy} = 620 kΩ
c. R_{wy} = 110 kΩ

Note: at the frequency once set, measure three voltages at three different output resistances

8.4. Assessment conditions

In order to pass the exercise it is necessary to:

- writing a short test at the beginning of the class with a positive result;
- doing the exercise;
- preparing a report according to the instructions below;
- defending the report on the next exercise;
- confirmation of mastering the scope of the exercise during the last final classes;

The report should be included:

- measuring card;
- transition characteristics of the amplifier;
- determination of amplifier gain for the linear part of the transition characteristic;
- describing the nature of distortions occurring for an excessive input signal along with an explanation of the reasons for their occurrence;
- amplitude-frequency characteristics of the broadband amplifier (on one graph) for two different coupling capacities, with the frequency axis drawn on the logarithmic scale;
- phase-frequency characteristics of a broadband amplifier (on one graph) for two different coupling capacities, with a frequency axis drawn on a logarithmic scale
- determination of the bandwidth of the broadband amplifier (marked on the graph) for two different coupling capacities;
- determination of gain in the broadband amplifier transmission band for two different coupling capacities;
- an explanation of how the coupling capacity affects the bandwidth and the shape of the bandwidth of the broadband amplifier;

- amplitude-frequency characteristics of the resonant amplifier for different load resistances (on one graph);
- determination of bandwidth for a resonant amplifier for different load resistances (check in the diagram);
- determination of amplification for the resonant frequency of the resonant amplifier for different load resistances;
- explaining why the addition of load resistance worsens the characteristics of the resonant amplifier;
- own conclusions and observations.

Guidelines for the report:

Bandwidth *B* we define any characteristic as the difference between the upper limit frequency f_g and the lower limit frequency f_d .

$$B = f_g - f_d$$

The frequency of lower and upper frequency bandwidth is defined as the frequency at which the level of the output signal is less than the maximum output signal by -3db or otherwise if the level of the output signal is about 0.707 lower the maximum output signal:

$$\frac{U_{WYMAX}}{U_{WY}(f_d)} = \frac{U_{WYMAX}}{U_{WY}(f_g)} = \frac{1}{\sqrt{2}} \approx 0.707$$

The gain of any characteristic can be defined as the ratio of the maximum output signal to the input signal

$$k_u = \frac{U_{WYMAX}}{U_{WE}} \qquad \left[\frac{V}{V}\right]$$

Often the amplification is expressed in decibels, then the reinforcement formula looks as follows:

$$k_u = 20 \log \frac{U_{WYMAX}}{U_{WE}} \qquad [dB]$$

8.5.1. Definition of the amplifier.

The amplifier is a system in which, at the expense of low electricity, it is possible to control more energy supplied from the power source to the receiver, i.e. to amplify the control signal. In other words, an amplifier is a device in which the energy from the power source is converted into the energy of an output signal in a way that depends on the input control signal. The amplifier must, therefore, have an active control element such as lamps - triode or pentode, or transistors - bipolar or unipolar. The active element controls the flow of energy from the power source to the load. The amplifier has an input circuit (input) to which a control signal is provided (amplified), has an output circuit (output) to which the amplifier signal is connected (load) - Fig. 8.5.1.

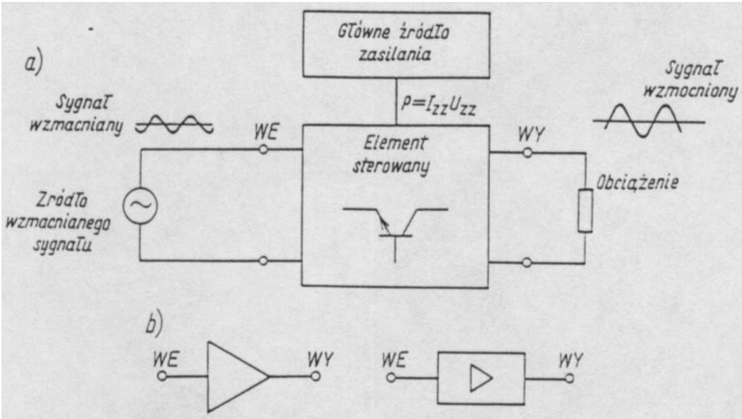


Fig. 8.5.1. Block diagram of the amplifier and its graphic symbols

An indispensable element of the amplifier operation is the power supply. In the amplifier the power of the input signal is increased, i.e. the product of $P=UI$. This can be achieved by increasing only one of the factors of this product, i.e. the amplification of I current or U.

8.5.2. Classification of amplifiers

Depending on the type of amplified electrical quantity, we distinguish between *current amplifiers* - the amplifier at the output amplifies the input current, the *voltage amplifier* - the amplifier amplifies the voltage signal and the most commonly used *power amplifiers* - the amplifier output produces appropriately amplified power input signal..

Depending on the used control element, the amplifiers can be divided into transistor and tube amplifiers used in the past, nowadays almost never before..

Assuming the division of the frequency range of the amplified signals as a criterion, there are distinguished between DC amplifiers (amplify direct current and signals from zero frequency) to a specific upper limb frequency, low frequency amplifiers (LF) and high frequency amplifiers (HF) – fig. 8.5.2. In electronics, an important feature of amplifiers is their ability to amplify only signals with frequencies lying in a narrow range, generally around a certain central frequency (the ratio of the upper frequency *fg* to the lower *fd* is close to unity). The amplification of these amplifiers is rapidly decreasing both for frequencies smaller and larger than the central frequency f_o. These amplifiers are called selective (often resonant). Another type of amplifiers enables amplified signals in the maximum wide frequency range (high value of the upper limit *fg* to lower *fd* in practice above 10). Such amplifiers are called broadband amplifiers.

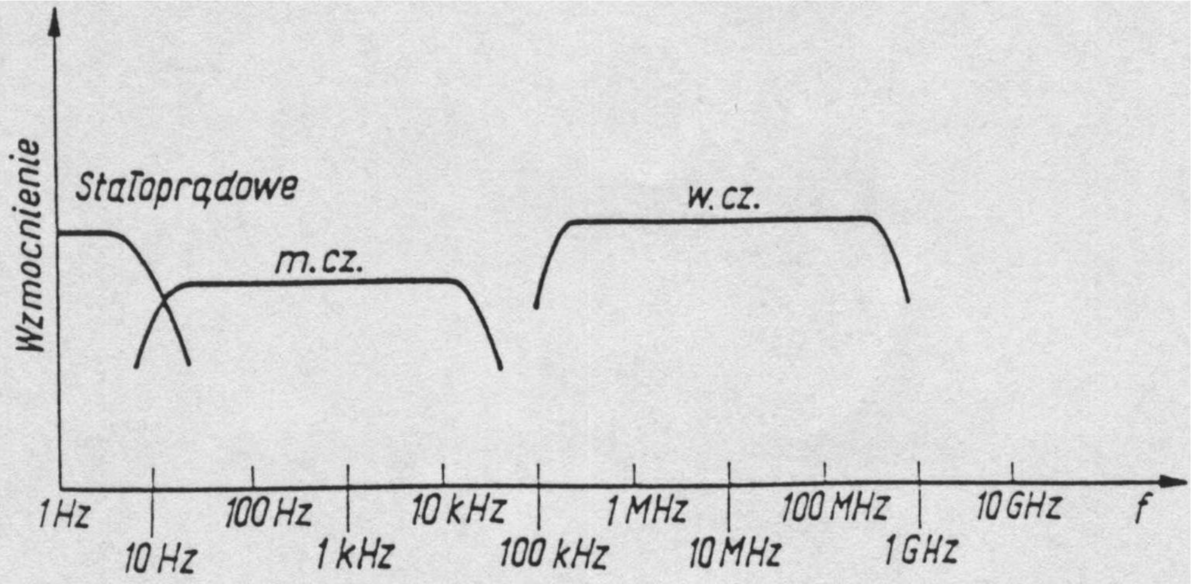


Fig. 8.5.2. Classification of amplifiers due to the range of amplified frequencies

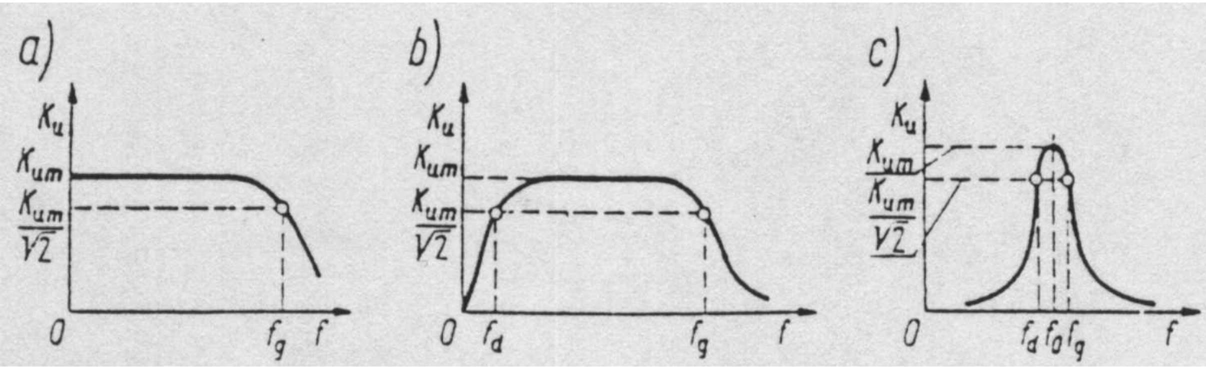


Fig. 8.5.3. Amplitude characteristics of a) direct current b) wideband c) selective

Amplifiers with capacitive coupling (RC), transformer coupling or direct coupling (galvanic) are distinguished according to the type of coupling used between amplifier and load (receiver, load) or the next amplifier stage. Only variable signals are amplified in RC and transformer feedback amplifiers, because the DC voltage from the stage output or signal source is not transferred to the step input (or load) by the coupling elements. These couplings are used, among other things, in acoustic amplifiers. In the case of direct coupling amplifiers, both constant and variable signals are amplified. These couplings are used, for example, in DC amplifiers.

Amplifiers are also classified according to the rest position of the operating point on the operating characteristics of the controlled element and the amplitude of the input signal. Class A, B, AB, and C amplifiers are distinguished. In class A amplifiers, the quiescent operating point is selected on the linear part of the operating characteristics of the controlled element (eg transistor), and the amplitude of the input signal is so small that the controlled element conducts the current (in the active range) throughout the entire period of the input signal. If the operating point is selected so that the controlled element conducts current only for half the period (for the second half of the period it is blocked), then the amplifier works in class B. In the AB class, the controlled element conducts the majority of the input signal period. In class C, the controlled element conducts for a smaller part of the input signal period. In class A, voltage amplifiers, both small and high-frequency ones, are built. Class B broadband power amplifiers are built in class B and selective power amplifiers in class C.

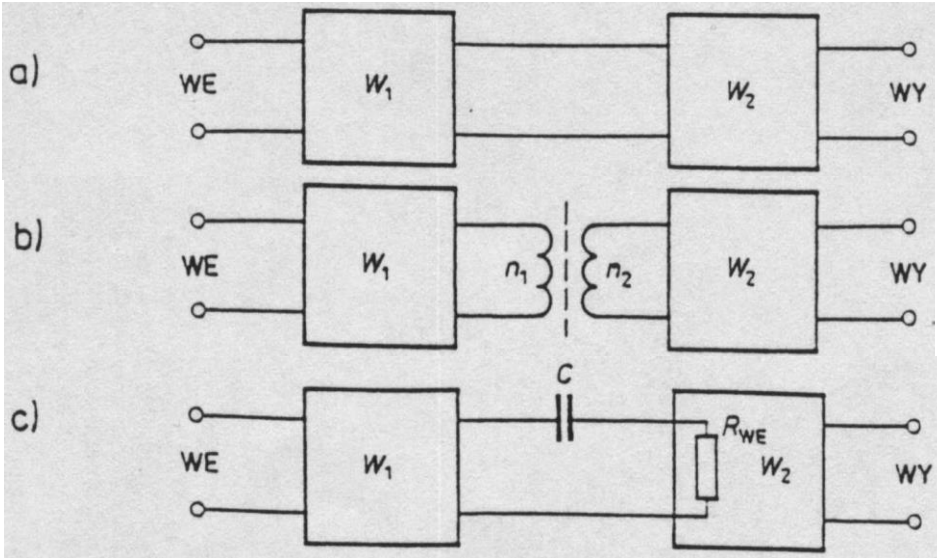


Fig. 8.5.4 Amplifiers with couplings: a) direct; b) transformer c) capacitive RC

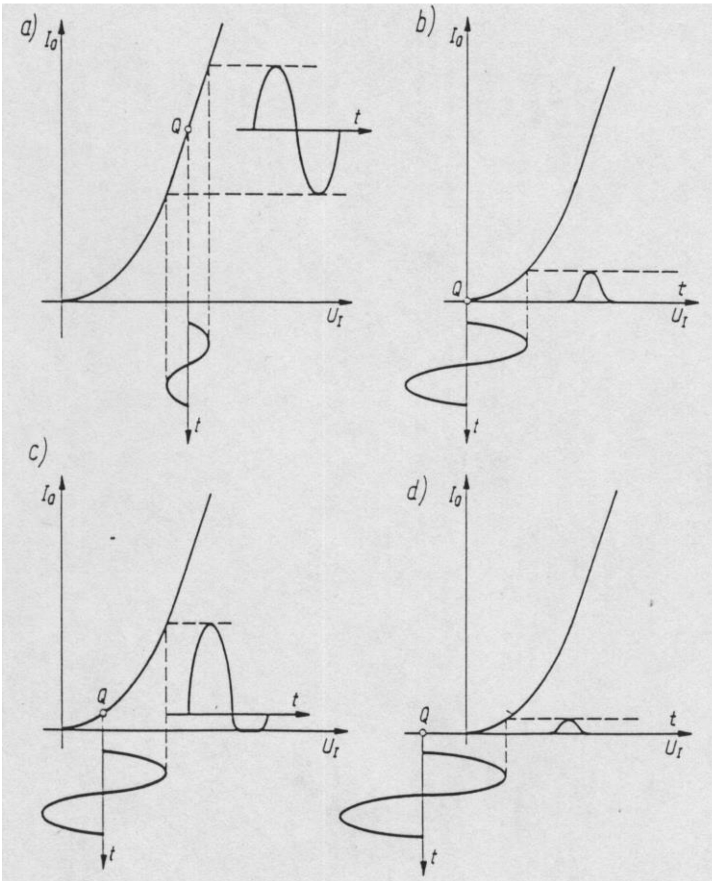


Fig. 8.5.5. Characteristics of the output current amplifiers *Io* as a function of the control voltage U_I due to the position of the operating point Q of the working part of the controlled element for class a) A; b) B; c) AB; d) C

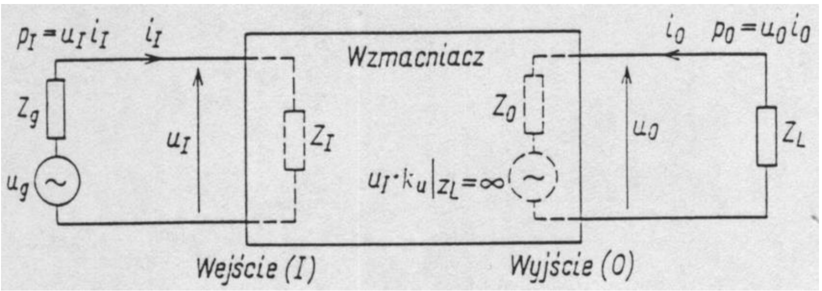
Class A amplifiers are characterized by the simplest structure, usually consisting of one active element, ie usually one transistor. They are also characterized by the lowest energy efficiency, because even in the absence of a control signal (the position of the Q point on the characteristic curve) the current is flowing through the active element. Class B amplifiers usually consist of two active elements, each of which conducts one half of the period of the amplified signal. This amplifier is characterized by higher energy efficiency. Because in the range of small values of input signals active elements are characterized by quite high non-linearity, the operating point of Class B amplifier (point Q) moves slightly above zero, thus eliminating signal distortion at the output of the amplifier. An AB class amplifier is then created. In class C amplifiers, many active components can be used, each of which can conduct a small part of the output signal. The energy efficiency of such an amplifier is then significantly increased.

8.5.3. Amplifier parameters

The basic parameters of the amplifiers are:

- amplification (power, voltage, current) $k_P(j\omega)$, $k_U(j\omega)$, k_I;$(j\omega)$;
- energy efficiency η;
- input impedance $Z_I(j\omega)$ (*I –ang, input- wejście*);
- output impedance $Z_O(j\omega)$ (*O –ang, output- wyjście*);
- rated input voltage, rated output voltage (or rated powers) U_{Izn}, U_{Ozn}, P_{Izn}, P_{Ozn};
- amplifier bandwidth *B*;
- dynamic range of amplifier operation *DW*;
- own noise level;
- level of linear distortion
- level of non-linear distortion.

Since most parameters are frequency dependent $\omega=2\pi f$, their frequency relationships are defined in many cases.



Rys. 8.5.6. Schemat zastępczy układu wzmacniającego

8.5.4. Amplifier amplification (amplifier gain)

The amplifier's voltage amplification k_u is called the ratio of the output voltage U_O to the input voltage U_I:

$$k_u = \frac{U_O}{U_I} \qquad (8.5.1.)$$

The current amplification of the k_i amplifier is called the ratio of the I_O output current to the input current I_I:

$$k_i = \frac{I_O}{I_I} \qquad (8.5.2.)$$

Power amplification is the ratio of power supplied to power load to input power:

$$k_P = \frac{P_O}{P_I} = \frac{U_O \cdot I_O}{U_I \cdot I_I} = k_u \cdot k_i \qquad (8.5.3.)$$

Amplification is often expressed logarithmically, with decibels as a unit (dB).

Reinforcements determined in dimensionless units may be converted to decibels according to the following equations:

$$k_u[dB] = 20\log\left|\frac{U_O}{U_I}\right| = 20\log|k_u| \qquad (8.5.4.)$$

$$k_i[dB] = 20\log\left|\frac{I_O}{I_I}\right| = 20\log|k_i| \qquad (8.5.5.)$$

$$k_P[dB] = 10\log\left|\frac{P_O}{P_I}\right| = 10\log|k_P| \qquad (8.5.6.)$$

8.5.5 Amplifier efficiency

The efficiency of an η amplifier is the ratio of the power that the amplifier gives to the P_O load to the total power that the amplifier consumes from the P_{ZZ} power source and from the P_I control signal source. Typically, the power of a signal taken from a signal source is negligible, the energy efficiency is the ratio of the output power to the power taken from the power source..

$$\eta = \frac{P_O}{P_I + P_{ZZ}} \approx \frac{P_O}{P_{ZZ}} \qquad (8.5.7.)$$

8.5.6. Input and output impedance

Input impedance Z_I is the ratio of input voltage U_I to input current I_I

$$Z_I(j\omega) = \frac{U_I(j\omega)}{I_I(j\omega)} \qquad (8.5.8.)$$

The output impedance Z_O is the ratio of the output voltage U_O at the unloaded output to the short-circuit output current. I_O

$$Z_O(j\omega) = \frac{U_O(j\omega)\big|_{Z_L=\infty}}{I_O(j\omega)\big|_{Z_L=0}} \qquad (8.5.9.)$$

For low and medium frequencies, where the phase shift between the voltages and the output currents is negligible, the imaginary parts of these impedances are close to zero.. In this case, it is possible to speak of input R_I and output resistors R_O:

$$R_I = \frac{U_I}{I_I} \qquad (8.5.10.)$$

$$R_O = \frac{U_O}{I_O} \qquad (8.5.11.)$$

Knowing the input and output resistance of the amplifier is particularly important for the conditions of matching the resistance. Optimal adjustment of the amplifier to the signal source and the load is achieved when the input resistance is equal to the source resistance and the output resistance is equal to the load resistance. It is allowed to connect to the amplifier a signal source with a resistance lower than the input resistance and a load greater than the output resistance. However, the opposite relationship between resistance is unacceptable, as it leads to distortion and in extreme cases can damage the amplifier..

8.5.7. Rated (nominal) output voltage, rated (nominal) output voltage

Nominal input voltage U_{Izn} (or input power P_{Izn}) is the value of input voltage (or input power) at which the amplifier gives off the output power P_{Ozn} (rated), specified by the technical requirements, or at which the rated output voltage U_{Ozn} is present. Most of the amplifier's parameters are given for the rated voltage (power) of the input. Otherwise we can say that the nominal values are the values at which the amplifier usually works and achives the given parameters.

8.5.8. Amplifier bandwidth.

The frequency response (bandwidth) is the frequency range of the amplified signals, for which the output power of the amplifier does not decrease below 50% of the power obtained in the middle of the band. The frequency response *B* of any amplifier is defined as the difference between the upper limit frequency f_g and the lower limit frequency f_d .

$$B = f_g - f_d \qquad (8.5.12.)$$

The lower and upper frequency limits are defined as the frequencies at which the output signal level is less than the maximum output signal by -3dB, or otherwise if the output signal level is less than approximately 0.707 times the maximum output signal:

$$\frac{U_{O\max}}{U_O(f_d)} = \frac{U_{O\max}}{U_O(f_g)} = \frac{1}{\sqrt{2}} \approx 0.707 \qquad (8.5.13.)$$

8.5.9. Dynamic range of amplifier operation

The dynamic range of the amplifier is called the permissible amplitude values of input signals (e.g. input voltages from U_{Imin} to U_{Imax}), for which the amplitude of the output signal is proportional to the amplitude of the input signal with a proportionality factor equal to amplification..

$$U_I = f(U_O) \qquad (8.5.14.)$$

For the input signal voltages smaller than U_{Imin}, the signal is masked by the own noise of the amplifier. U_{Imin} is most often determined by the level of the own noise of the amplifier. For input voltages greater than U_{Imax}, the output signal from the amplifier will be unacceptably distorted, as due to overloading of the active element its gain will decrease. The dynamic range of the amplifier is determined by providing its transient amplitude characteristic or the ratio of the maximum voltage to the minimum voltage:

$$D_W = \frac{U_{\mathrm{Im}ax}}{U_{\mathrm{Im}in}} \qquad (8.5.15.)$$

8.5.10. Amplifier characteristics

Characteristics of amplifiers are one of the most commonly used elements defining their parameters. We can distinguish several types of characteristics:

- amplitude-frequency;
- phase-frequency;
- dynamic (transient);

8.5.11. Frequency characteristics - amplitude and phase

The amplitude characteristics determine the frequency dependence of the amplifier amplification, k_u=f(f). There is a frequency on the abscissa axis, usually on a logarithmic scale. There is a voltage, current or power gain on the axis of the ordinates. Sometimes during testing of the amplifier on the *Y* axis, we draw the output voltage U_O at a constant level of input voltage U_I = const. At a specific frequency or in a specific frequency band, the characteristic reaches the maximum defined as k_{umax}. In the amplitude characteristics, the amplifier bandwidth B, and the lower and upper limit frequencies f_d

and f_g can be marked..

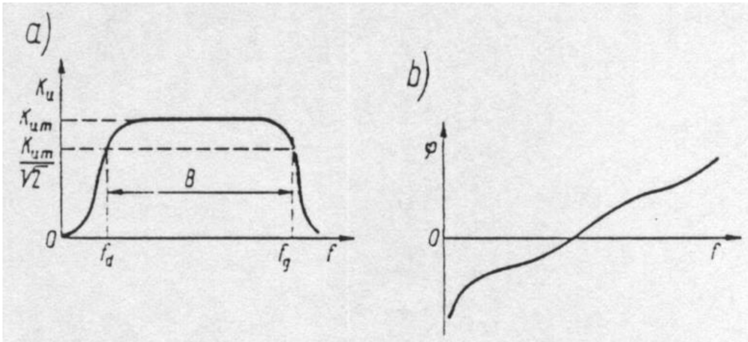


Fig. 8.5.7. Frequency characteristics of amplifiers: a) amplitude; b) phase.

The phase characteristics of the amplifier $\varphi = f\ (f)$ determine the phase shift between the input and output signals. In addition, you can observe an offset between the amplified signals at different frequencies. This is particularly important in determining the linear distortion of the amplifier.

8.5.12. Dynamic characteristics

The dynamic characteristic called the transient characteristic shows the relation of the output voltage to the input voltage. $U_O = f(U_I)$. The U_{Imin} and U_{imax} input voltage ranges, the U_{omin} and U_{omax} output voltage ranges for which the amplifier has constant gain, can be read out. The minimum input voltage is determined by the self-noise level of the amplifier. The maximum, however, depends on the active element of the amplifier. For some values of the output voltage the amplifier seems to be *"saturated"*. A further increase of the input voltage above U_{imax} will no longer cause an increase of the output voltage, additionally distorting its shape.. An example of a transition characteristic is given in Figure 8.5.8.

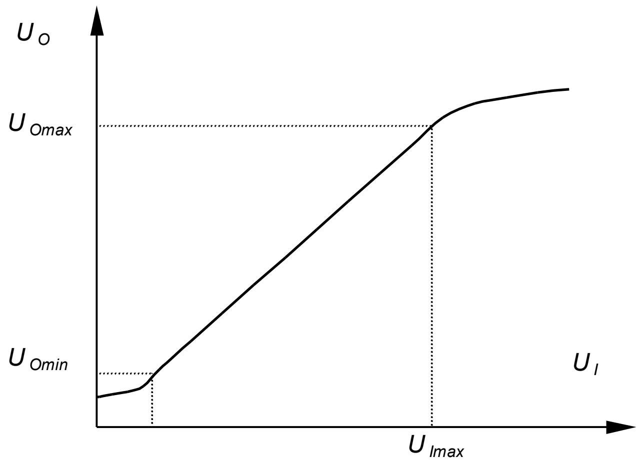


Fig. 8.5.8. Dynamic (transient) characteristics of the amplifier

8.5.13. Linear distortion of the amplifier

In each amplifier there are elements whose transmission properties depend on the frequency or on the resting operating point and amplitude of signals. Reactance elements are the cause of uneven amplification and different phase shifts of individual harmonic components of the amplified signal. This changes the shape of the amplified periodic signals (if they are not harmonic) even if there are no non-linear elements in the amplifier circuit. This type of distortion is called linear distortion. (Fig.

8.5.8) Distortions of the signal caused by uneven amplification of its harmonic components are called frequency distortions. Distortions of the signal due to uneven phase shift of the individual harmonic components of the signal are called phase distortions.

The phase characteristic of the amplifier is used to evaluate these distortions. If for an amplifier the angle of phase shift is proportional to frequency, such an amplifier does not introduce phase distortions, i.e. it does not change the shape of amplified signals (depending on phase shifts) but only shifts the signal in time.

The permissible values of frequency and phase distortion depend on the purpose of the amplifier. For example, it is acceptable to accept frequency distortions from several decibels (2-4dB) for acoustic amplifiers to tenths or hundredths of decibels for measuring amplifiers. Phase distortion is negligible in acoustic amplifiers because the human ear practically does not capture it, but it is very important in measuring amplifiers. An amplifier without linear distortion should has equal amplitude characteristics and constant or linear phase characteristics over its operating frequency range..

8.5.14. Non-linear distortion of the amplifier

The elements with non-linear current and voltage characteristics (transistors, transformers) present in the amplifier cause other types of signal shape deformations, called *non-linear distortions*. These distortions are the effect of amplifier amplification dependence on the amplitude of the amplified signal, which is why they are also called amplitude distortions. With a sinusoidal input signal, the output current is not sinusoidal. It is distorted, so it is a waveform consisting of the frequency of the input signal (basic) and the components of the current with higher frequencies, which are multiples of the fundamental frequency. The spectrum of the output signal contains, next to the fundamental component, the higher order harmonics. The more the shape of the output signal deviates from the sinusoid, the amplitudes of its harmonic components are bigger and there are more of them in the output signal. Therefore, non-linear distortions of the amplifier and its non-linearity are assessed by the following factors k_h. It is equal to the ratio of the effective value of harmonic voltages (or currents) at the output with the basic frequency:

$$k_h = \frac{\sqrt{U_2^2 + U_3^2 + \ldots}}{U_1} \qquad (8.5.16.)$$

where: U_1, U_2, U_3, ... – amplitudes or effective values of the first, second, third, etc. harmonic output voltages.

Because the non-linear current-voltage characteristics of the amplifiers are usually non-linear, the amplifiers exhibit deformations called intermodulation. They are the result of mixing (modulating) on a non-linear basis the two components of the input signal of different frequencies (e.g. harmonic). In the output signal with different frequencies, unwanted components appear at frequencies equal to the sum and frequency difference of the input signal components.

8.5.15. Multistage amplifiers

If a gain greater than that achievable in a single amplifying stage (single stage amplifier) is required, then multi-stage amplifiers, ie consisting of several single stages, are used. In such amplifiers, individual amplifying stages are connected so that the output voltage of the previous stage is simultaneously the input voltage of the next stage. This combination of individual amplification stages is called a cascade connection. Individual stages can be connected directly (the output of the previous stage is galvanically shorted to the input of the next stage) - it is a direct coupled amplifier, capacitively (the output of the previous stage is connected via a capacitor of sufficiently large capacity with the input of the next stage) - it is an amplifier with capacitive coupling or transformer (output signal of the previous stage is transformed by the transformer to the next stage input) - it is an amplifier with transformer coupling.

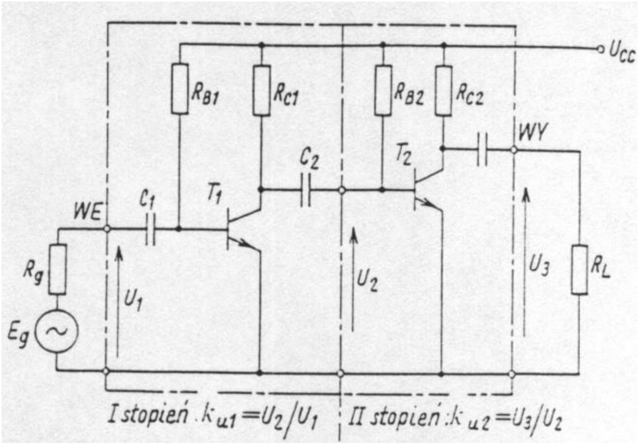


Figure 8.5.9. Diagram of a two-stage amplifier with capacitive coupling

In a two-stage capacitive coupling amplifier (Fig. 8.5.9.), the resistors R_{b1} and R_{c1} and R_{b2} and R_{c2} are the polarization circuits that determine the resting point of the transistors T_1 and T_2. The C_2 coupling capacitor was used to separate the DC voltages present in the first and second stage (the operating points of these stages are independent of each other), while the C_1 and C_3 capacitors separate the DC voltages present in the amplifier from the signal source and the load (The signal source and the load do not affect the operating point of the transistors T_1 and T_2).

The gain of the two cascaded steps is equal to the product of the amplifications of the individual steps. k_{u1} i k_{u2}. On basis on fig 8.5.9. we may observe:

$$k_u = \frac{U_3}{U_1} = \frac{U_2}{U_1} \cdot \frac{U_3}{U_2} = k_{u1} \cdot k_{u2} \qquad (8.5.17.)$$

Because the gain module is often expressed in logarithmic units, you can write:

$$20\lg|k_u| = 20\lg|k_{u1} + 20\lg|k_{u2}|| \qquad (8.5.18)$$

or:

$$(k_u)_{dB} = (k_{u1})_{dB} + (k_{u2})_{dB} \qquad (8.5.19)$$

From the properties of the logarithmic function it follows that the resultant gain of the amplifier expressed in dB is equal to the sum of the gains expressed in decibels of individual stages.

8.5.16. Construction of the simplest one-stage amplifier

The simplest amplifier built on a single transistor is the common emitter (EC) amplifier, which consists of one bipolar transistor. *npn* (Fig. 8.5.10.).

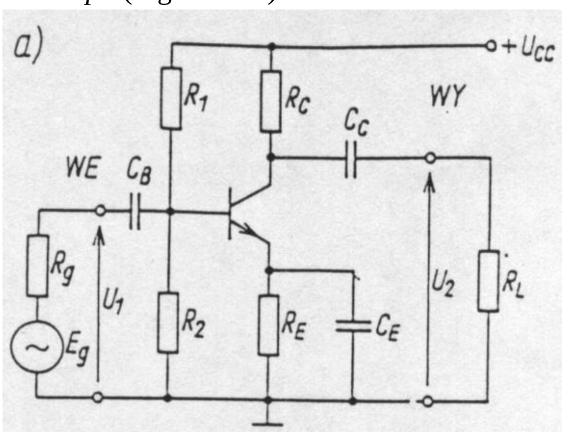


Fig. 8.5.10. Diagram of the amplifier in the EC circuit

The resistances R_1, R_2, R_E, R_C form a DC polarization circuit of the transistor defining its resting point of operation, where $R_C + R_E$ is at the same time the static load (for DC currents) of the transistor. Resistance R_E, included in the DC loop of the negative feedback, provides stabilization of the operating point. The purpose of a C_E-capacity interlocking capacitor is to connect a variable signal to ground For a signal frequency f at which the capacitance reactance of the $1/2\pi f C_E$ capacitor is close to zero, there is no negative feedback for the variable signal in the circuit. The capacities C_B and C_C cause that the source of the amplified E_G signal as well as through the resistances of the R_L load do not flow constant currents, but only the amplified signal. Thus, the signal source and the load are separated from the transistor for DC voltage and do not affect its resting point.

8.5.17. Power amplifiers

In addition to increasing the amplitude of the signal (voltage or current), each amplifier also has power amplification. A power amplifier is an amplifier whose task is to deliver to the load (e.g. a loudspeaker in acoustic amplifiers) an adequately high useful power of the amplified signal. These are usually amplifiers with high current amplification and low (usually close to 1) voltage amplification. Therefore, the steps preceding the power amplifier shall provide a signal of sufficient amplitude to control it.

The main operating parameters defining the power amplifier properties are:

- • maximum useful output power of the P_{omax} signal;
- energy efficiency η, determined by the effect of useful power output to the power supplied from the power source;
- non-linear distortions determined by the harmonics content in the output signal with a sinusoidal excitation at a given frequency;
- bandwidth and shape of amplitude-frequency characteristics.

When designing power amplifiers, we strive to provide the required usable output power of the signal, with the highest possible energy efficiency of the system and possibly the smallest non-linear distortion.

Classification of power amplifiers takes into account two basic criteria:

- the location of the transistors' resting point on the $Ic(U_{BE})$ transition characteristic; four classes of amplifiers are distinguished:A, B, C i AB.
- type of amplifier output coupling with load; transformer coupling (separating constant and load components) and transformerless coupling (capacitive or direct).

8.5.18. Basic requirements for power amplifiers

The basic requirements for power amplifiers, i.e. high output power with maximum energy efficiency and minimal distortion, are based on the following design features. The parameters and the degree of power utilization of the amplifier (transistor) depend on the adopted amplifier's operating class. At the transition from class A, through AB, B to C, the energy efficiency and the degree of power consumption of the transistor increases, but non-linear distortions increase. For this reason, only Class A, AB and B classes are used in low frequency (acoustic) power amplifiers. Class C, due to high distortion, is used only in selective high frequency power amplifiers, in frequency multiplier circuits.

8.5.19. Selective amplifiers

Selective amplifiers (or bandpass, mediumpass) are called amplifiers that only amplify signals with a frequency in a narrow range (band) around a certain center frequency f_0, and effectively suppress signals outside this range. Amplifiers with such properties should have adequate selective amplitude-frequency characteristics. The ideal amplitude and frequency characteristics of a selective amplifier would be those of a rectangular shape, as shown in Fig. 8.5.11 with a dashed line. Because such a characteristic is not possible in practice, so the deviation of the actual and ideal characteristics is determined by the so-called the p-aspect ratio, which is a measure of the amplifier's selectivity. Next to the width of the bandwidth Δf and center frequency f_0 this is one of the most important parameters, defined by the formula:

$$p = \frac{\Delta f}{\Delta f_{20}} \qquad (8.5.20.)$$

where Δf is the frequency interval specified for the drop of the gain module by 3 dB below the gain module k_0 for central frequency f_0 (i.e. for value $k_0/\sqrt{2}$) - this is the frequency response of the amplifier, Δf_{20} (that is, to value $k_0/10$) – Fig-8.5.11a.

a) b)

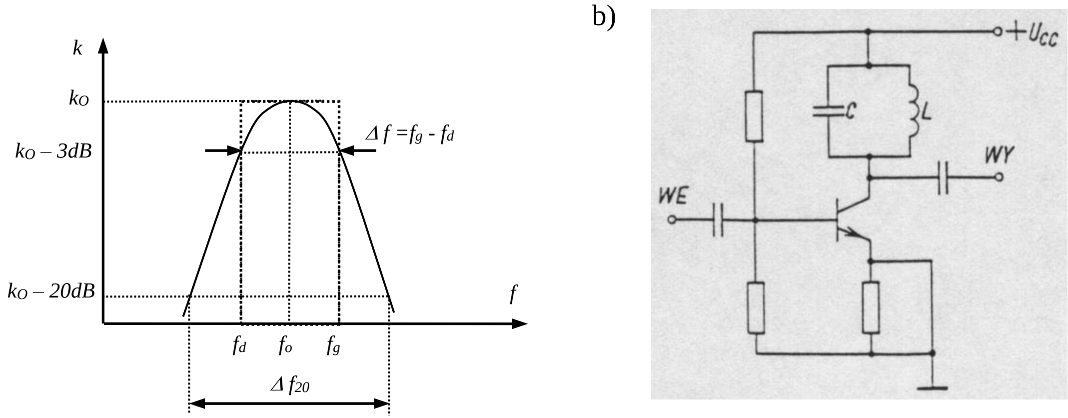


Fig. 8.5.11. Selective amplifier a) amplitude-frequency characteristics
b) scheme of the simplest selective amplifier built on the resonant circuit LC

Selective amplifiers are used when it is necessary to isolate and amplify signals with frequencies contained in a specific band. However, the required bandwidth depends on the purpose of the amplifier. If the task of the amplifier, such as in a selective voltmeter, is to extract only one frequency signal from a signal with a wider spectrum, the frequency response should be as small as possible. In another case, when a video signal should be separated, the frequency response should be wider. The term selective amplifiers refers to a large group of amplifiers with different central frequencies, e.g. or LF or HF, different bandwidth and selectivity. The properties of selective circuits included in its signal gain path or feedback path determine the course of the frequency characteristic of a selective amplifier..

8.5.20. Negative feedback in the electronic system

Feedback is when a part of the system output signal is fed back to its input. If this part of the output signal (feedback signal) is shifted in phase by 180 degrees in relation to the input signal of the U_I, i.e. has the opposite phase (Fig. 8.5.12), then the effective input signal of the U_I is reduced, the output voltage of the U_O is reduced, and thus the amplification of the circuit is also reduced.

$$k_f = \frac{U_O}{U_I} \qquad (8.5.21.)$$

In this case, we say that there is a negative feedback in the system. This type of feedback is used in most amplifiers and control systems, as it mainly stabilizes their bandwidth and improves other system parameters. If the phase shift between the feedback signal and the input signal is equal to 0 degrees (or 360 degrees), i.e. these signals have a matching phase (figure 8.5.12.c), then the effective input signal U_I is increased, which results in an increase in the output signal U_0 so the U_0/U_{If} gain (transmittance) increases. Such feedback is called "positive feedback" and is most commonly used in many oscillator and generator systems.

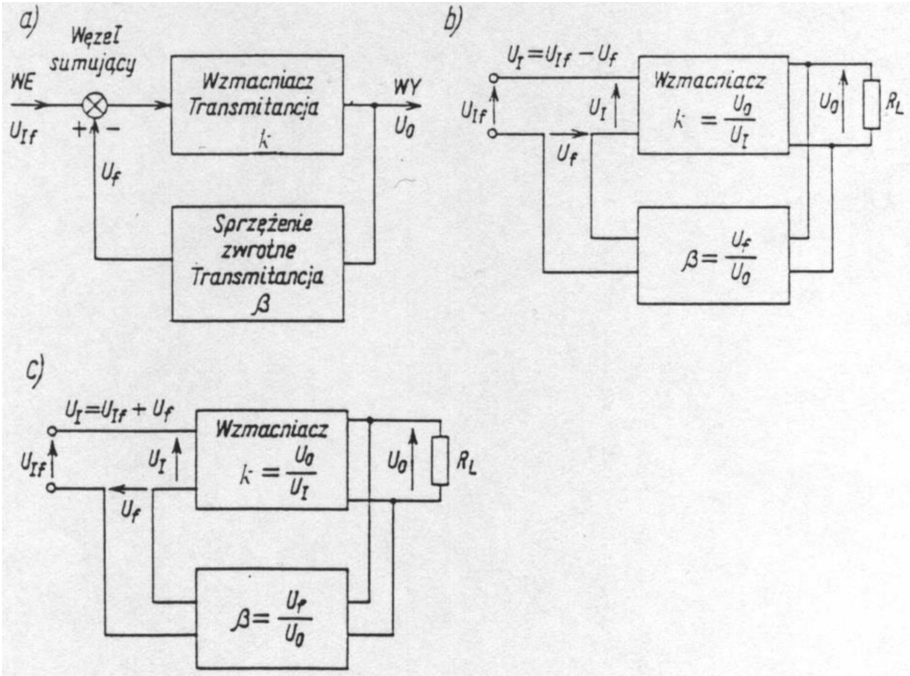


Fig. 8.5.12. a) General block diagram of the feedback system; b) an example of negative feedback; c) an example of positive feedback.

The output voltage U_0 can be saved as:

$$U_O = U_I \cdot k = \left(U_{If} \pm U_f\right) \cdot k \qquad (8.5.22.)$$

Substituting:

$$U_f = \beta \cdot U_O \qquad (8.5.23.)$$

and dividing both sides of the equation by U_{If} and noting:

$$k_f = \frac{U_O}{U_{If}} \qquad (8.5.24.)$$

we get a general relationship, right for feedback systems:

$$k_f = \frac{k}{1 \pm \beta \cdot k} \qquad (8.5.25.)$$

where:

- k_f - amplification of a closed-loop feedback system, i.e. the resulting amplification of the feedback amplifier;
- k - amplification of the open feedback loop system, i.e. gain without feedback;
- β - transfer function (transmittance) of the feedback path.

The "+" sign in the denominator is for the negative join, the "-" sign for the positive.

The analysis of this relationship shows that if the product $k\beta$ - called the feedback loop gain - is for a system with negative feedback much more than 1, that is when $k \Rightarrow \infty$, this is the amplification of the system with feedback $k_f = 1/\beta$, i.e. it is defined only by the transmission properties of the feedback path.

However, for systems with positive feedback, the gain is increased, but the stability is deteriorated and oscillations in one of the frequencies of the operating range are possible in the system when $k\beta = 1$.

8.5.21. The purpose of using negative feedback in systems

Negative feedback has a very positive effect on most amplifier parameters:

- improves the stability of the amplifier (the system is less sensitive, e.g. to fluctuations of supply voltages and temperature changes);
- reduces noise and distortion (both linear and non-linear):
- increases the upper limit frequency and decreases the lower limit frequency, extends the amplifier's bandwidth;
- allows the formation of frequency characteristics;
- allows you to modify the input and output impedance.

A side effect, sometimes undesirable, is the reduction of amplification.

8.5.22. Classification of negative feedback

Negative feedback is classified according to how the feedback signal is received from the circuit output and how it is delivered to the inputThe feedback signal can be proportional to the output voltage, in which case it is referred to as a voltage feedback, or output current, in which case it is referred to as a current feedback. When the feedback signal is fed into an input in series with an input signal, this is called serial, and when in parallel it is called parallel. There are four basic systems with negative feedback:

- voltage-series;
- voltage and parallel;
- current and parallel;
- current-series.

8.5.23. The influence of negative feedback on the parameters of the amplifier

The formula for the negative feedback voltage amplification shows that in the case of strong feedback, the value of the product of $\beta \cdot k_u$ It is much greater than unity, and therefore the formula simplifies to the form:

$$k_{uf} = \frac{k_u}{\beta_u \cdot k_u} = \frac{1}{\beta_u} \qquad (8.5.26.)$$

which causes that the gain of the amplifier ceases to depend on the parameters of the amplifiers and depends only on the resistance in the feedback system. This is the basis for the construction of operational amplifiers with very stable amplification.

Negative feedback distortion is reduced as many times as gain is reduced.:

$$k_{hf} = \frac{k_h}{1 + \beta_u \cdot k_u} \qquad (8.5.27.)$$

where:

- k_{hf} - distortion coefficient in the negative feedback circuit,
- k_h - distortion coefficient in the non-feedback circuit.

The lower limiting frequency of the negative feedback band is reduced by the following formula:

$$f_{df} = \frac{f_d}{(1 + \beta_u \cdot k_u)} \qquad (8.5.28.)$$

The upper limit frequency is increased:

$$f_{gf} = f_g \cdot (1 + \beta_u \cdot k_u) \qquad (8.5.29.)$$

where:

- f_{df}, f_{gf} – the lower and upper frequencies of the bandwidth in the negative feedback system,
- f_d, f_g the lower and upper frequencies of the bandwidth in the system without feedback.

Input and output resistance with negative parallel coupling is reduced.

$$R_{If} = R_I \cdot (1 + \beta_u \cdot k) \tag{8.5.30.}$$

$$Z_{If} = Z_I \cdot (1 + \beta_u \cdot k) \tag{8.5.31.}$$

and increased with serial coupling:

$$R_{If} = \frac{R_I}{1 + \beta_i \cdot k_i} \tag{8.5.32.}$$

$$Z_{If} = \frac{Z_I}{1 + \beta_i \cdot k_i} \tag{8.5.33.}$$